RESUMÉ

A system of solar energy conversion is shown which will generate electrical power from the sun's energy. This power may either be used directly to operate electrical equipment or it can be used to charge a battery which will store the energy for continuous operation. The modular assembly of this system makes it possible to install the system with a minimum of difficulty and the system engineer can design the solar power supply for any amount of power in multiples of 5 watts. A method of calculation is shown which will allow the engineer to closely estimate the amount of electrical energy to be expected from an installation in any part of the world.

HISTORY

Since the beginning of time, Man, with varying degrees of reverence, has worshipped the sun or recognized that the sun was the source of many of Man's needs. Although ancient people attributed many things to the sun, both good and bad, most of them did not realize that without the sun there could be no life as we know it on Earth. Without the sun the Earth would be a cold, lifeless sphere drifting aimlessly through space.

A story of the first scientific use of the sun's power comes to us as a legend. Archimedes in the year 214 B C. is supposed to have used the sun's rays to burn the Roman Armada attacking Syracuse. He focused the rays to obtain heat by the use of reflecting mirrors. Since Archimedes' time, Man has tried to use the sun's heat in many ways. During recent years several heat engines which transform the heat of the sun into rotary or push-pull motion have been built. Most of these systems have a rather low efficiency and must have expert maintenance in order to operate. About a hundred years ago scientists discovered that some of the metallic elements had a property of converting sunlight into

electricity when a certain mixture of the elements was exposed to sunlight. The most suitable of these early elements, selenium, has long been a part of the familiar "photo-electric exposure meter". Although the efficiency of selenium is limited to about 1 %, by the use of a very sensitive meter and a large cell, an acceptable reading can be obtained in dim light. In 1954, while involved in transistor research, Drs. Chapin, Fuller and Pearson discovered that silicon, when properly treated, could be used as a photoelectric element with an efficiency as great as 6%. In 1955, the Bell Telephone Laboratories announced that they could further improve this 6% figure to a conversion efficiency of about 11 % This means that from each square yard of silicon solar converter area exposed to sunshine one may expect about 110 watts of power. This amount of power is well worth considering in our present day economy as this power is available day after day for each hour the sun is shining and the power can be easily transferred into storage batteries where it is available for use whenever necessary.

During 1955, the Semiconductor Division of Hoffman Electronics Corporation was engaged in the manufacture of silicon diodes. The silicon solar cell was adopted for production in the Semiconductor plant and the solar cell became available in quantities. Since the introduction of the Silicon Solar Cell to the commercial market by the Semiconductor Division, production techniques have been continuously improved until cells with efficiencies as high as 14 % have been produced.

SOLAR CONVERTER FIELD TESTS

There have been many field tests of photovoltaic solar converters since the photovoltaic effect was first observed in 1839. The elements used in these early experiments were only capable of efficiencies in the order of 1 % and, therefore, required a very large surface area to develop an appreciable amount of power. This large area and the element's characteristics of deteriorating after a few years use, contributed to the high cost of construction and a high maintenance cost. The early field tests proved the solar converters to be economically infeasible for large scale power generation.

The first feasibility study of a silicon solar converter was carried out by the Bell Laboratories during 1955. The converter was installed on a telephone pole in Americus, Georgia and proved that the relatively small area of silicon converters could provide power for operation of telephone lines. As there is no appreciable deterioration of the silicon from aging and as there is no part of the solar cell destroyed during operation, it will last indefinitely. The silicon solar cell thus proves to be an economically feasible device which, once installed, will provide power for hundreds of years.

Using the new high efficiency, low cost Silicon Solar Cells during 1956 and 1957, the Hoffman Electronics Corporation constructed and installed many silicon solar power supplies to prove economic feasibility and to gather operation and installation data. The largest silicon solar power supply which has been built to date was installed and tested with the cooperation of the U. S. Forest Service. The panel contained approximately 500 square inches of silicon converters and was mounted on a California mountain top in the Cleveland National Forest. This panel was designed to operate in conjunction with recording equipment to charge a standard automotive battery in a fire lookout tower. The battery was attached to a radio receiver-transmitter connected to operate as a relay station for all Forest Service messages originated by the forest rangers in the surrounding area. The

total capacity of the storage battery was sufficient for 8 days of "receiving only" time or sufficient for 13 hours of "transmit only" time. The solar converter furnished power for continuous operation over a period of four months which included both receiving and transmitting time on the system. At the end of the four month period the system was still operating and was only removed because it was considered a complete success and further tests during the season when transmit time would be small were considered to be unnecessary.

From the largest to the smallest of the other solar power systems which have been built and tested for various purposes all of them have been entirely successful. The smallest system, a flashlight containing rechargeable batteries recharged from the sun's energy, was operated for one half hour each day and the unit left in the sun to replenish the charge in the batteries. The test was discontinued after one year of operation with the batteries still operating the flashlight. In a similar test without the solar charger, the batteries were dead after 11 days of operation under these conditions.

Although the electrical system for the solar power supplies was successful, during the construction and installation of the mechanical portions, it was realized that the simpler methods could be used to advantage. A new design has been developed to take advantage of simpler construction and to make wiring and installation at the site as simple and as foolproof as possible.

In order to allow as much flexibility of power supply design as is commensurate with simplicity, the new power supply modules are furnished as five-watt units. As many of these five-watt modules as are deemed necessary by the engineer in charge can be used in combination to furnish any amount of desired power. Each unit is identical and measures 12" x 20" x 3/4" in size. It is of cast aluminum and consists of an aluminum tray, an insulator on which the solar cells are mounted, and a glass cover plate. For installations in special areas, the glass cover may be ordered in special thicknesses or materials to withstand collisions by large hailstones or wind-borne objects. The glass cover as normally supplied is commercial grade soda lime sheet. The module elements may be mounted by means of a 1/4" bolt in each of the corners.

Accessory electrical equipment to form a complete solar power supply is contained in an accessory module element. The accessory module is the same size and shape as the basic five-watt module and is designed to mount on the same frame as the converter modules. One part of the accessory unit is an interconnection panel. This portion of the accessory module consists of a number of terminal blocks arranged to allow easy interconnection of the individual solar module outputs to achieve desired voltage combinations. The final combined output is connected to the control portion of the accessory module. The control elements are a relay and a back current diode. The diode functions to prevent current developed by the storage battery from flowing back through the solar cells when the cells are not illuminated by sunshine. As there is a voltage drop across any diode that can be put in the circuit, an appreciable power loss could be realized in the diode. In order to obtain as much power from the converter as possible, a relay is used to short out the diode during the time that the solar unit is providing a high charge. This relay is operated by solar cells connected directly to the relay coil. These cells are

separate from the solar power supply cells and their sole purpose is to close the relay when the illumination is bright. Although the diode could be left out of the circuit with but a small power loss, its use provides a desirable element of safety As the relay contacts are the only mechanical moving parts in the entire system, the diode will provide an alternate current path if the relay becomes inoperative because of mechanical failure. The battery to be charged is connected to the output terminals on the accessory module.

POWER DETERMINATION

As the amount of energy contained in sunshine varies from place to place and during different months of the year, the five-watt rating of these modules means that five-watts or more of power is available at the terminals of the converter when the surface is exposed to approximately one Langley* of sunlight energy The amount of power that can be expected from installations in various locales of the Unites States and from many different places in the world can be very closely estimated by the use of climatological data issued by the United States Weather Bureau. These reports list solar incidence in Langleys at the recording stations. An estimate of power to be expected during any period may be made by referring to records of previous years. If, for example, a particular location is listed as receiving an average of 459 Langleys per day during October, this is equivalent to 7.65 hours of sunlight per day at a rate of 1 Langley per minute During October then, approximately 38.25 watt hours of energy would be expected from a single 5-watt module each day. In the case of more modules, each module would give this amount of energy to the circuit each day. The same module in a location receiving a lesser amount of energy,

* One Langley = 1 gram calorie per square centimeter.

such as 203 Langleys per day, [illegible]

Although these Langley readings [illegible]

Solar Cells are not direct[illegible]

equipment and differences of angle [illegible]

that the Weather Bureau Langley readings are usable [illegible]

tion engineer.

SAMPLE CLIMATOLOGICAL DATA

Portions of Weather Bureau Climatological Data are illustrated.

HOURLY READINGS

Madison, Wisconsin
Langleys per Minute

SUN'S ZENITH DISTANCE

Date	A. M.					P. M.			
	78.7°	75.7°	70.7°	60.0°	*	[illegible]	[illegible]	[illegible]	[illegible]
October									
1	.93	1.02	1.13	[illegible]	[illegible]		-	-	-
2	.84	.97	1.11	1.24	1.30	[illegible]	.60	[illegible]	.41
-									
-									
27	.87	.98	1.15	Clouds	1.35	[illegible]	1.15	1.03	.91
-									
-									
Average	.91	1.02	1.14	1.27	1.33	1.19	.99	.87	.72

DAILY READINGS AND WEEKLY AVERAGES

LANGLEYS PER DAY

Daily Readings	Albuquerque, New Mexico	Madison, Wisconsin
October 1st	556	441
October 2nd	561	425
-	-	-
-	-	-
October 27th	283	322

Daily Average Week of		
October 7th	459	395
October 14th	341	263
October 21st	353	203
October 28th	372	309

TYPICAL SOLAR POWER SUPPLY

A solar power supply system capable of furnishing approximately 1/2 ampere at 6 volts continuously 24 hours a day and year after year, would consist of three 5-watt module elements, and one accessory module These units are mounted on a frame which is tilted so as to receive the maximum sunshine. The output connectors of the accessory module are connected to a storage battery mounted in a convenient location. In a locale which averages a five hour or 300 Langley sun day, this 15-watt system will develop approximately 75-watt hours of power. This is equivalent to 12.5 ampere hours at 6 volts. Stored and consumed continuously, this amounts to an average current of slightly over 1/2 ampere.

CHARACTERISTICS

Five-Watt Solar Module

Size:	12" x 20" x3/4"
Weight:	8 lbs.
Material:	Aluminum body with glass cover
Mounting:	Clearance holes for 1/4" bolts in four corners.
Connections:	Positive and negative terminals are brought out to 1/4" screws insulated from the case.
Voltage Output:	Available connected for charging either 6, 12, or 24-volt batteries. (Nominal)
Illumination Required for Rated Output:	1 gram calorie per centimeter squared impingent perpendicular to the surface of the converter elements at 25° C.

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